

An aerial photograph of San Francisco Bay and the surrounding coastal system. The Golden Gate Bridge is visible in the center. Overlaid on the photograph is a color-coded map representing sediment transport. The colors range from blue (low transport) to red (high transport), with the highest concentrations along the coastlines and in the Golden Gate strait. The map shows the flow of sediment from the mountains and hills into the bay and then out to sea.

# Sediment Transport in the San Francisco Bay Coastal System

Patrick L. Barnard<sup>1</sup>, Li H. Erikson<sup>1</sup>, Amy Foxgrover<sup>1</sup>, Edwin Elias<sup>1,2</sup>,  
James R. Hein<sup>1</sup>, Mary McGann<sup>1</sup>, Robert Rosenbauer<sup>1</sup>, Kira Runtzel<sup>1</sup>,  
Peter Swarzenski<sup>1</sup>, Renee Takesue<sup>1</sup>, Florence Wong<sup>1</sup>, and Don Woodrow<sup>1</sup>

<sup>1</sup>USGS, Pacific Coastal and Marine Science Center, Santa Cruz, CA, USA, [pbarnard@usgs.gov](mailto:pbarnard@usgs.gov)

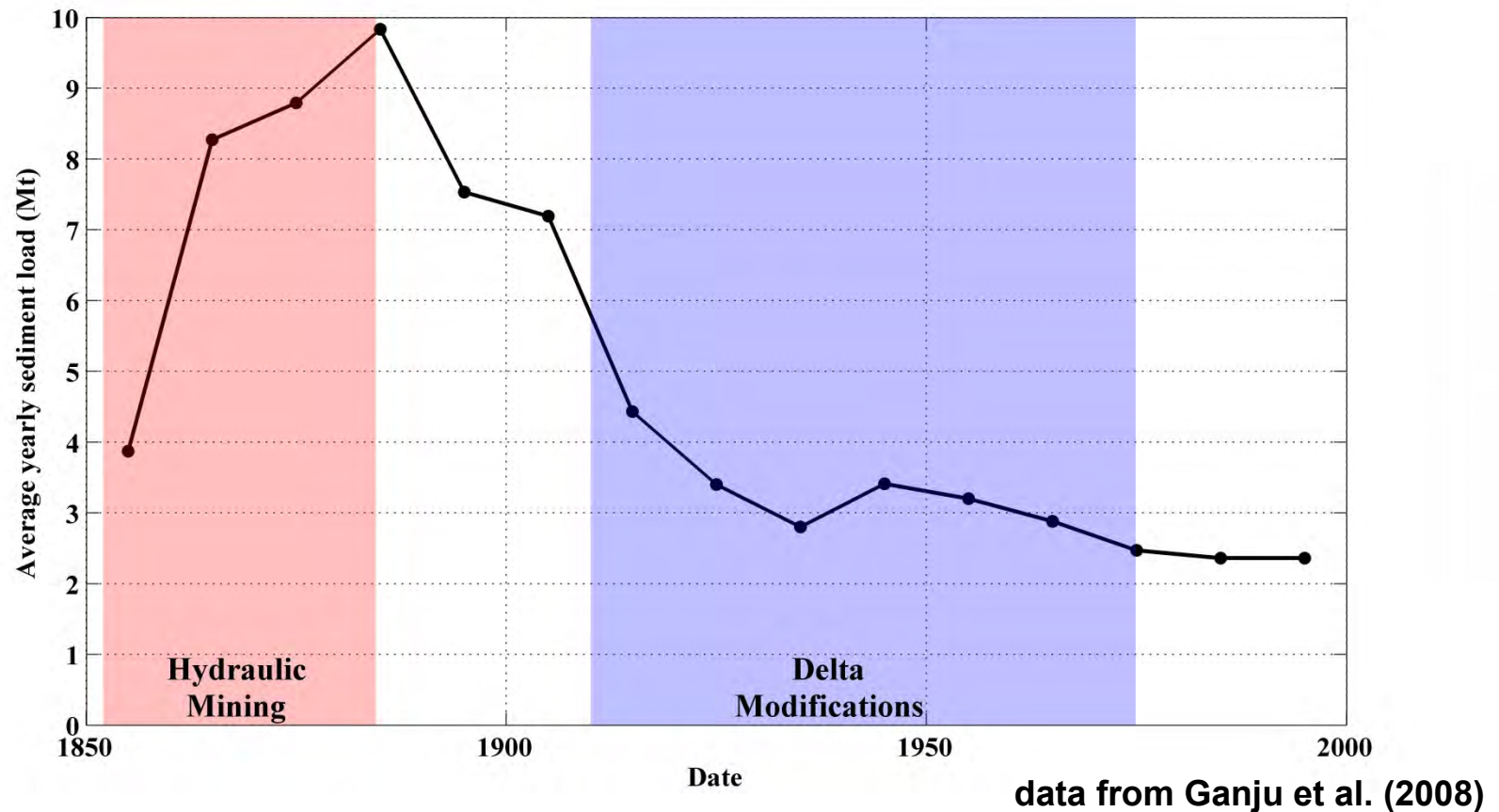
<sup>2</sup>Deltares, Delft, The Netherlands





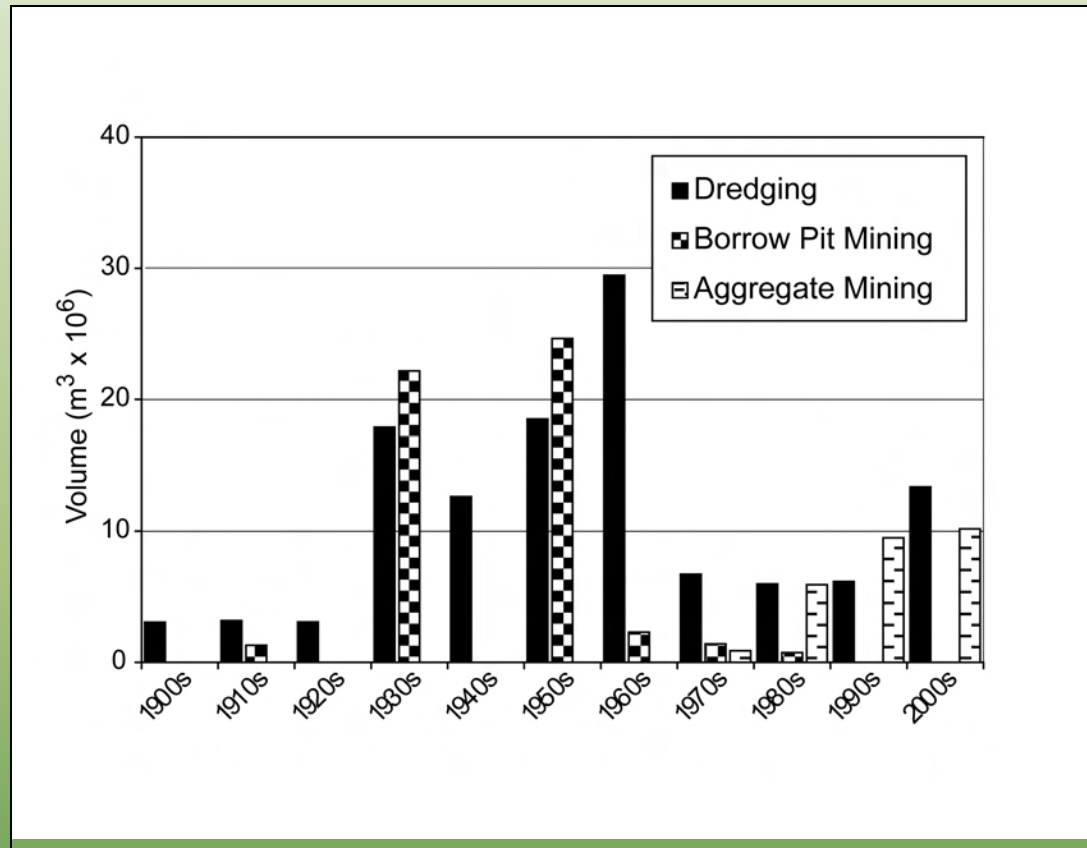


# Sediment Supply Changes



- Sharp decrease in suspended sediment concentrations observed inside the Bay around 2000 = 'erodible sediment pool' depleted (Schoellhamer, 2011)
- Using both a low and high-end emissions scenario through 2100, Cloern et al. (2011) project reduced fluvial discharge from the Delta and a decline in suspended sediment concentration

# Sediment Removal



- 200 million  $\text{m}^3$  of sediment removed from system
  - 113 million $^3$  from Central Bay
  - 75 million $^3$  identified as sand (50 million $^3$  from Central Bay)
- Records incomplete
  - Missing many borrow pit mining records
  - No aggregate mining records pre-1974 (began in 1930's)





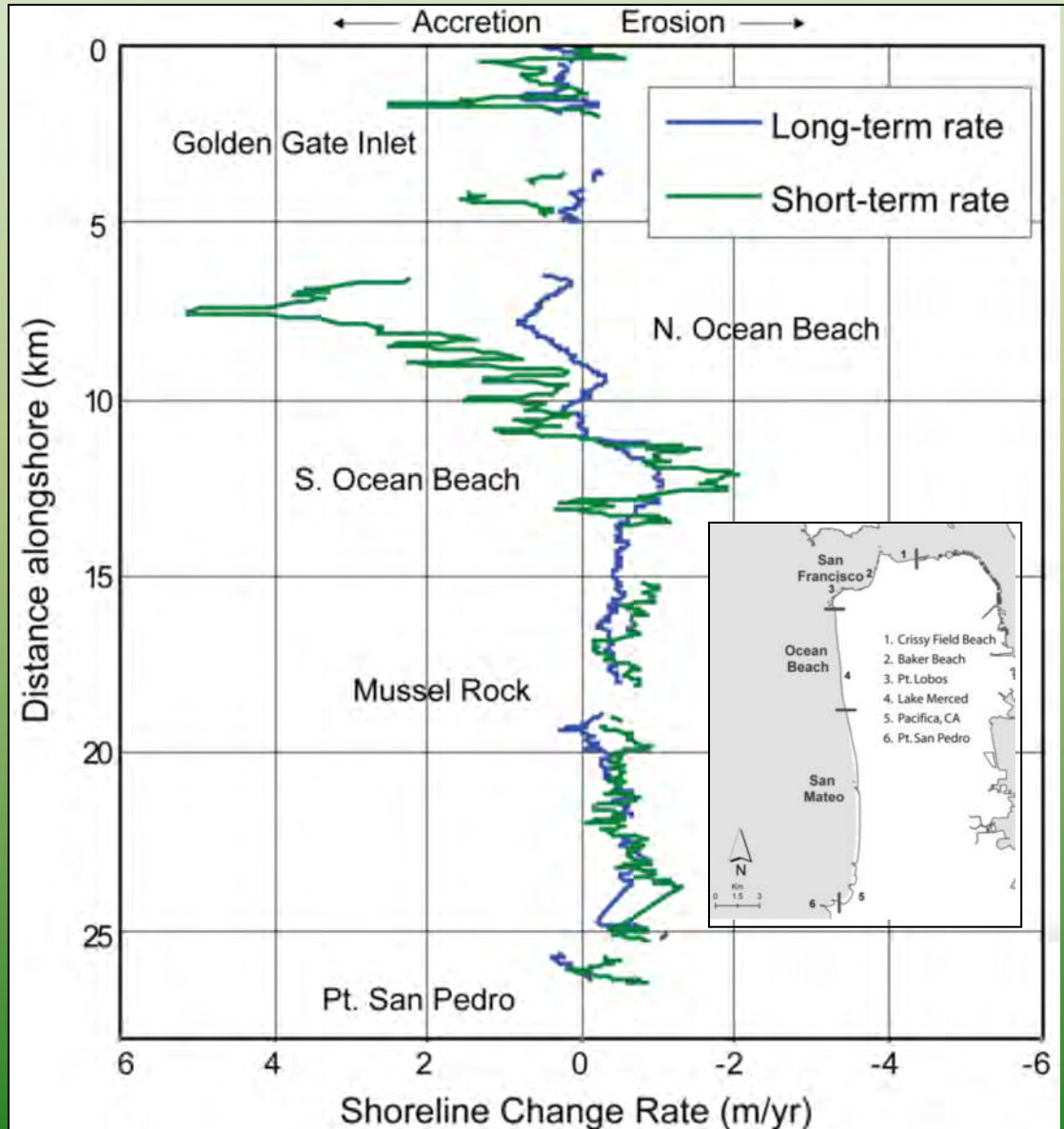
# Historical Changes







# Regional Shoreline Changes



- Most rapidly retreating coastline in California
- Shift to erosion where SF Bar attaches at Ocean Beach
- San Mateo region strongly erosional in long-term (93%) and short-term (98%)
- In SM region rate of erosion increased by 50% from long to short term





# Summary of Sediment Supply

- Net sediment deposition of over 350 million m<sup>3</sup> in the Bay between 1856 and 1887 due to hydraulic mining
- Construction of dams, reservoirs, flood-control bypasses, and bank protection in the 20th century trapped and/or reduced the transport of sediment to the Bay
- The majority (~86%) of the sediment load to San Francisco Bay was supplied by the Delta from 1909 to 1966
- By the end of the 20th century, sediment supply to the Bay from the Delta and local tributaries was ~equal
- Aggregate mining currently removes ~1 million m<sup>3</sup>/year of sediment in Central Bay and Suisun Bay
- Dredging removes ~3 million m<sup>3</sup>/year of sediment out of navigation, with the majority of this material permanently removed from San Francisco Bay

\*Summarized in: Barnard, P.L., Schoellhamer, D.H., Jaffe, B.E. and McKee, L.J., 2013. Sediment transport in the San Francisco Bay Coastal System: an overview. *Marine Geology*, Special Issue San Francisco Bay, Volume 345, p. 3-17

<http://dx.doi.org/10.1016/j.margeo.2013.04.005>



# Volume Focused on Sediment Transport

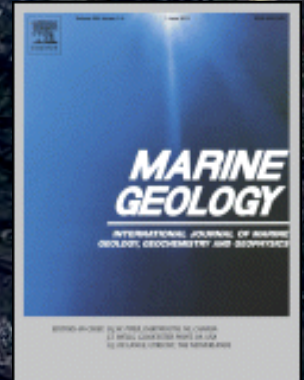
**Special Issue of *Marine Geology*** (full volume publication  
November 22, 2013, all papers available online)

**Theme:** A multi-discipline approach for understanding sediment transport and geomorphic evolution in an estuarine-coastal system: San Francisco Bay

**Guest editors:** P.L. Barnard, B.E. Jaffe and D.H. Schoellhamer

## **Highlights:**

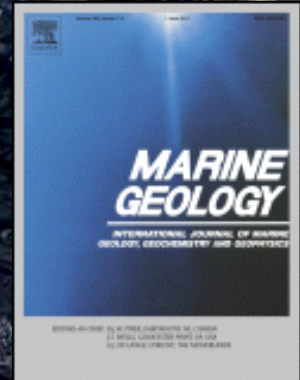
- 21 papers
- state-of-the art in coarse and fine sediment transport research





# Key Findings from Special Issue

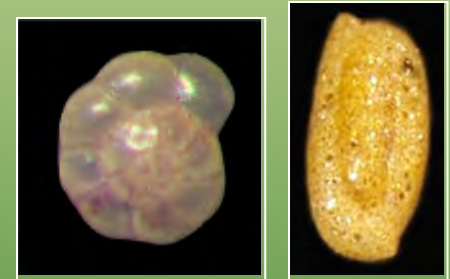
- **McKee et al.:**
  - Small tributaries covering 5% of the watershed area, supply 61% of the sediment
- **Schoellhamer et al.:**
  - Large flows that could result in major sediment transport events are at the upper limit of what the Sacramento Valley flood control system is designed to allow
- **Erikson et al:**
  - Observed net flux of suspended sediment seaward through the Golden Gate
  - Sediment pulse transports estimated to take 8 to 12 days from Suisun to Central Bay
- **Hestir et al:**
  - Suspended sediment has been declining over the past 30 years as a result of declining sediment supply, contributing to dramatic changes in the ecology and geomorphology of the estuary
  - The upper estuary erodible sediment pool is currently depleted, flushed dramatically during the 1982-83 El Niño floods



# Sand Provenance Study Approach

Objective: Apply multiple approaches to identify the source and pathways of beach-sized material in the San Francisco Bay Coastal System

- Proxy techniques
  - Bedform asymmetry
  - Numerical modeling
  - Current measurements
- Direct sampling and physical characteristics
  - Morphometric analyses (grain size, shape, sorting, etc.)
  - Foraminiferal analysis
- Geochemical analysis (fine-medium sand)
  - Isotopes,  $^{143}\text{Nd}/^{144}\text{Nd}$  and  $^{87}\text{Sr}/^{86}\text{Sr}$
  - X-ray diffraction
  - Heavy minerals
  - Rare Earth Elements









# Bedform Morphology

**5% net ebb asymmetry based on ~45,000 bedform measurements**

# Numerical Modeling- Annual Transport

**Modeled transport significantly agrees with bedform measurements (~76%)**



# Provenance Sampling

**253 samples collected for provenance**

# Surficial Grain Size

713 samples collected from 2005-2012







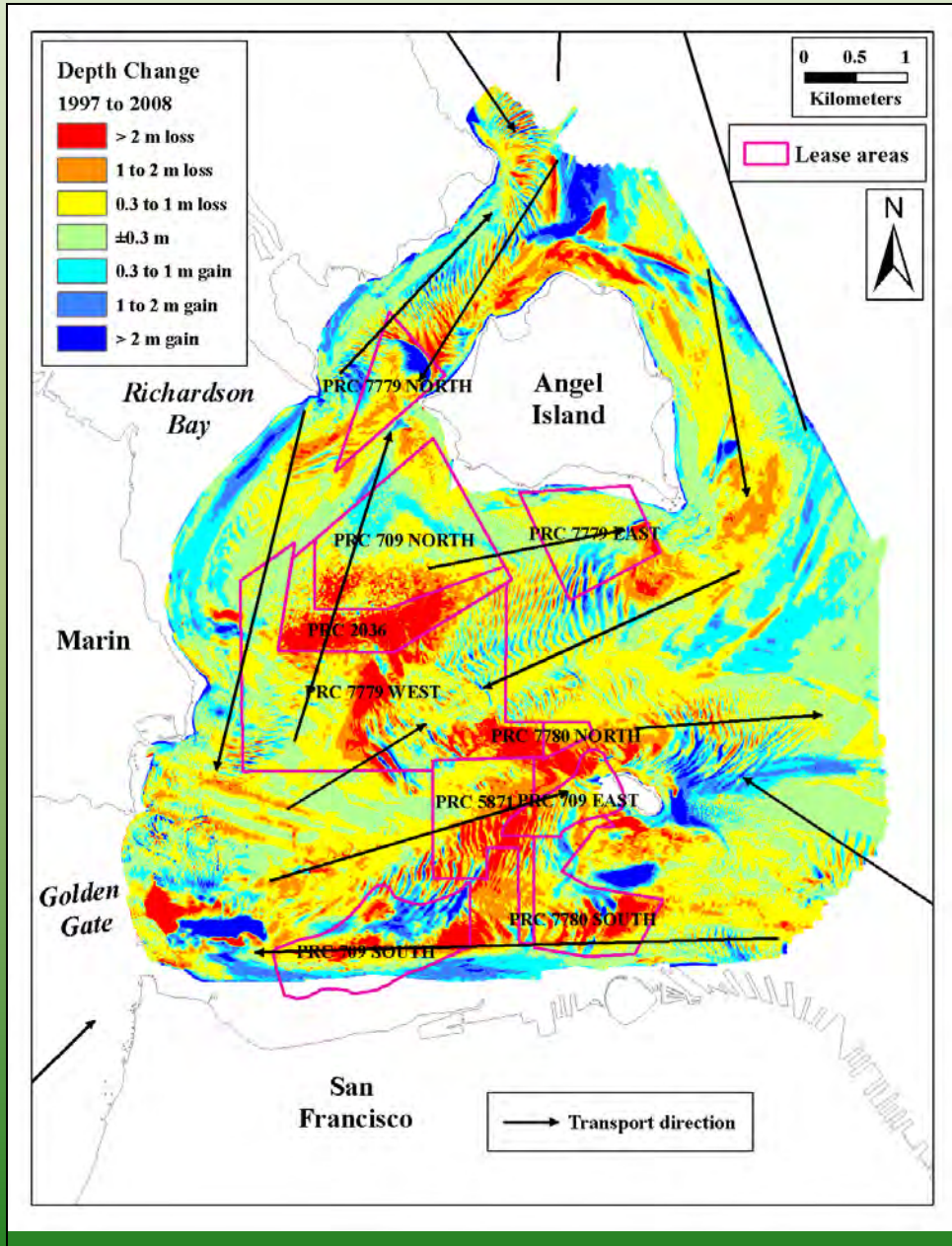








# 1997-2008 Bathymetric Change



- 10.8 million m<sup>3</sup> of sediment was removed by aggregate mining from 1997-2008 (total loss of 14.1 million m<sup>3</sup>)
- ~3-fold increase in rate of erosion (-3.2 cm/yr) from 1947-1979 change analysis (Fregoso et al., 2008)
- Lease sites lost sediment at a rate 5 times higher than rest of study area
- No borrow pit mining or dredging was performed in this area from 1997-2008
- 85% of sediment removed was not naturally replenished
- Established pathways support selective management



# Conclusions

- Pervasive loss of sediment from the San Francisco Bay Coastal System over the last 50 years, driven by anthropogenic impacts
- Reduction in sediment supply from the Delta via the Bay to the outer coast drives shrinking of the ebb tidal delta and regional coastal erosion
- An integrated multi-technique approach for assessing provenance, featured in special issue of *Marine Geology*
- The Sierras are still the primary source of sand in the system- further limits on this source will likely further reduce supply to area beaches, stressed additionally by projected sea level rise



Project Website: [http://walrus.wr.usgs.gov/coastal\\_processes/](http://walrus.wr.usgs.gov/coastal_processes/)